Experimental Uncertainty and Measurement Errors in Hydraulic Engineering

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Abstract

The Task Committee on Experimental Uncertainty and Measurement Errors was formed to provide information and guidance on current practices used for describing and quantifying measurement errors and experimental uncertainty in field and laboratory hydraulic measurements. Hydraulic engineers in both practice and research measure a host of static and dynamic hydraulic variables including velocities, pressures, displacements, temperatures, fluxes, etc. Errors associated with these measurements arise from both systematic and random sources. Additionally, the measurement devices employed by hydraulic engineers are numerous, and often technically sophisticated. The Task Committee will produce a monograph which describes (1) sources of error in hydraulic measurements; (2) types of experimental uncertainty; and (3) procedures for quantifying error and uncertainty. The Task Committee welcomes the input from interested parties.

Introduction

When any physical quantity is measured, one concern is always how close the measured value is to the "true" value (ASCE 1993). The ASCE Technical Committee on Hydraulic Measurements and Experimentation (TCHME) identified experimental uncertainty and measurement error associated with hydraulic measurements as a technical area where guidance is needed. This seemingly straightforward objective is complicated by the fact that hydraulic engineers are involved in a wide variety of measurements using a vast array of devices. Measurements of flow rates in closed conduits and open channels are examples of similar measurements which are made using very different measurement devices based on distinct methodologies.

Hydraulic Engineers are involved in a wide spectrum of activities including hydromachinery, environmental fluid mechanics, erosion and sedimentation, irrigation and drainage, and hydrology. Involvement in such diverse works indicates a wide range of scales of interest. Engineers working in hydromachinery or physical modeling take measurements at small scale, while engineers working in open channel

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flows and hydrology take field measurements on larger scales (ranging from individual river cross-sections to entire watersheds). Recent publications in hydraulic engineering have often failed to address the issues of measurement error and experimental uncertainty.

Experimental uncertainty arises because direct measurements of phenomenon of interest are often impractical. Measurements are often made of related variables, and fundamental differential equations are used to estimate the phenomena of interest. For instance, discharge estimates in a river are made based on point estimates of velocity. The point estimates are integrated over the cross section yielding the flow rate estimate. While research on the effects of vertical velocity gradients on mean velocity estimates is extensive, errors regarding the influence of secondary flow or the horizontal spatial resolution of sampling stations are largely unknown.

All measurements are encumbered by systematic and random errors which can be significant. From this common point, similarities between measurement techniques begin to diverge. Often, discharges in scale hydraulic models are estimated using orifice or venturi meters which can have significant errors in the range of 3% to 5%. Laser Doppler velocimeters (LDV) are used to measure point velocities in regions of interest, which are compared with mean velocities calculated from the lower accuracy discharge measurement. This contradiction illustrates the inconsistency in error and uncertainty introduced by using data from two different instruments.

There can be significant economic impacts associated with experimental uncertainty and measurement error. Mattingly (1983) reported that 20 trillion cubic feet of natural gas were metered through approximately 42 million flow measurement devices in 1978-79. At a cost of $2.00 per cubic foot, a measurement error of 0.01% represents a potential economic loss (or gain) to the supplier of $4 billion.

Scope of Committee Work

The Task Committee on Experimental Uncertainty and Measurement Errors in Hydraulic Engineering was formed to provide information and guidance on current practices used for describing and quantifying measurement errors and experimental uncertainty in field and laboratory hydraulic measurements. Hydraulic engineers make measurements of flows, velocities, and ancillary variables in both research and engineering practice. Table 1 presents a partial list of measurements made and measuring equipment used by hydraulic engineers:

This incomplete list provides evidence of an incredible array of measurement technologies in use by hydraulic engineers today. The uncertainty of a measurement by one of the above devices is a separate issue from the accuracy of the measurement. In reality, the uncertainty is a result of a particular application and experimental setup. The experimental uncertainty is particularly important in physical hydraulic models, where uncertainty in the model may mask undesirable behavior in the prototype.

Table 1.

MEASUREMENT	DEVICE
Position	Tape, Transit, Electronic Distance Meter (EDM), Total Station, Geographic Positioning System (GPS)
Velocity	Float, Pitot, Hot Wire, Hot Film, Propeller Meter, Electromagnetic Flow Meter, Laser Doppler Velocimeter (LDV), Ultrasonic Flow Meter, Dilution, Tracers, Particle Image Velocimetry (PIV).
Discharge	Integrated Velocities, Orifice, Venturi, Elbow meters; Weirs, Turbine meters, Tracers.
Pressure	Manometers, Pressure Transducers.
Sediment Size	Sieves, Visual accumulation tube, Hydrometer, Filter Paper.
Suspended Sediment Concentration	Instantaneous, Point, and Depth-Integrating Samplers.
Bed Material	BM-54, Drag Sampler
Bed Load Sediment	Helly-Smith sampler.
Rigid-body Displacement	Float, Point or Hook Gage, Linear Variable Differential Transformer, Potentiometer, Video Methods, Ultrasonic- and Laser-based methods, Capacitance and Conductance Probes.
Torque	Dynamometer.
Force	Force Transducer (strain gages), Balance.
Power	Dynamometer.
Vibration	Accelerometers.
Temperature	Thermometer, Resistance Temperature Detector, Thermistor, Thermocouple, Infrared remote sensing.
Rainfall	Sight Gage, Weighing and Tipping Bucket Gauge, Optical Rain Gage, Weather radar, Satellites.
Soil Moisture	Mass methods, Time-Domain Reflectrometry (TDR), Satellites.
Atmospheric Variables	Hygrometer, Sonic Anemometer, Radiometer, Evaporation Pan,
pH, Dissolved O_2, BOD	Numerous methods...
Voltage/Current	Multimeter, Power Analyzer, Oscilloscope, PC-based Analog-Digital Converters.

TC Goals

The objectives of the Task Committee on Experimental Uncertainty and Measurement Errors are to:

- Compile information on general types of measurement errors in hydraulic engineering-- in both field and laboratory settings.
- Review available techniques for estimating experimental uncertainties, and demonstrate application of these techniques to typical hydraulic engineering problems.
- Prepare a draft report (monograph) on the topic of Measurement Errors and Experimental Uncertainty in Hydraulic Engineering.
- Prepare a draft policy statement regarding quantification of measurement error and experimental uncertainty in papers occurring in the Journal of Hydraulic Engineering, and submit to the Publications Committee for consideration.
- Prepare and submit the final copy of the special publication on Quantification of Measurement Error and Experimental Uncertainty in Hydraulic Engineering and submit to ASCE.

Conclusions

Few studies published in recent hydraulic engineering literature have quantified the potential measurement error associated with hydraulic measurements, or described the uncertainty associated with the measured results. The consequences of experimental uncertainty on conclusions reached by the interpretation of the experimental data is seldom acknowledged (ASCE 1995).

Identification of experimental uncertainty and potential sources of measurement error associated with specific types of measurements is a critical problem in hydraulic engineering. Furthermore, there is a need for improved techniques to describe and quantify errors and uncertainty in research and engineering analysis. The newly-formed Task Committee on Experimental Uncertainty and Measurement Errors will help to promote the discussion of these issues within the hydraulic engineering community.

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References

ASCE, 1993, Guidelines for PC-based data acquisition systems for hydraulic engineers, Monograph- Task Committee on Data Acquisition Systems of the Hydraulic Engineering Division of the American Society of Civil Engineers.

ASCE, 1995, Task Committee Proposal by Technical Committee on Hydraulic Measurements and Experimentation (unpublished).

Mattingly, G.E., 1983, Volume flow measurements *in* Goldstein, R.J., ed., Fluid mechanics measurements: Washington, D.C., Hemisphere Publishing Corporation, p. 245-306.